DEVELOPMENT AND APPLICATION OF HIGH-TEMPERATURE AIR-COMBUSTION TECHNOLOGY IN LOCAL INDUSTRIES

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ABSTRACT

Since global climate-change agreements were made in Kyoto, Japan, CO_2 reduction and imposition of NOx pollution fees have become energy and environmental policy in Chinese Taipei. Because of this, sustainable improvement in energy savings through significant enhancement in heat recovery has become very effective. This paper illustrates the experience of ITRI (Industrial Technology Research Institute) in developing highly efficient regenerative burners (HRS) and applying them in local industries. In summary, the scale-up design of gas-fired regenerative burners is established, and high energy recovery is successfully exhibited on industrial furnaces, demonstrating that high-temperature air-combustion technology may provide local industries an alternative to achieve high-efficiency utilization of fossil energy with low pollution.

INTRODUCTION

High temperature air combustion (HiTAC) technology is a unique phenomenon resulting from highly efficient heat recovery using cross-exchange regenerative burners in a short time changeover. This concept was invented and developed in 1980 and has recently been in

practical use [1-2]. Since HiTAC was unveiled by NFK (Japan) [3], in addition to many Japanese domestic companies [4–5], several institutes worldwide have become involved in this advanced research [6–10]. Theoretically, HiTAC is characterized by stabilized flame, low-NOx emission and uniform heating, but as yet, successful industrial applications are found mostly in heating furnaces, as shown in Table 1. In a pie chart showing local CO_2 contributions, industrial heating accounts for 41%, creating pressure to reduce energy consumption. HiTAC technology has been introduced to determine the extent of energy savings in order to meet the target for CO_2 reduction in the industrial heating process [11]. A schematic diagram of a regenerative burner is shown in Figure 1; the basic components are a burner tile, regenerator and cross-exchange mechanics. During a cycle of operation, when the alternative flame is switched synchronically with turning of cross-exchange mechanics (CEM), fresh air is brought into contact with regenerators in one burner and is subsequently heated up to only 30–50 C heat loss[12]. Simultaneously, hot flue gas is induced to release heat to the regenerator on the other burner, and is finally emitted with cooled exhaust. The temperature efficiency of regenerative material is expressed by a ratio of the sensible heat absorbed by the preheated air to that of the flue gas released to the regenerative material. In other words, the efficiency of 0.90–0.94 is obtained without bypassing the flue gas, depending on the cycle time [13].

ERL/ITRI began to engage in HiTAC technology in 1996 and has built testing facilities for both gas-fired and diesel-oil-fired units, as shown in Figure 2. Testing furnaces to identify the best assembly of regenerative burners, ERL/ITRI subsequently carried out component research, completing several successful technical demonstrations, to exhibit the advantage of high energy savings for local industries. In summary, ITRI has established a scale-up capability on various regenerative burners, and is ready to demonstrate high energy savings and pollution control in collaboration with local industries.

DESCRIPTION OF RESULTS

1) Component and performance testing

In the ERL/ITRI facility, the major components of gas-fired regenerative burner include the burner body, honeycomb ceramic regenerator (150mm W x 150mm L x 50mm H) and cross-exchange mechanics (CEM); in order to establish scale-up criteria, a regenerative burner with 10×10^4 Kcal/h capacity is used to test different fuels based on a limitation of the furnace geometry [15]. In other words, a constant-velocity theory is adopted during scale-up to obtain flame stability first, then flame width and length is further modified based on heating requirements to meet local regulations for NOx emissions. Since burners are maintenance-driven, it is better to identify compatible key parts that can be replaced readily with local-made products to reduce cost. In this presentation, the pilot burner, UV flame-detector and signal amplifier of the burner body are successfully demonstrated as capable of localized maintenance.

1.1) Design and performance testing of pilots

A commercial pilot shown in Figure 3 was observed to exhibit overheating on the surrounding surface due to a premix of air and gas before ignition that enhances the combustion reaction. As a result, the enhancement causes a quick release of chemical energy and in turn heats up the wall of the metal tube immediately; this overheating phenomenon has been observed most frequently when the air/fuel ratio is around 1/1. To overcome this problem we design a new pilot, shown in Figure 3, that introduces partial cool air to quench the surface near the high-temperature flame to avoid overheating of the metal tube.

Investigations of the operation and adjustment functions for two different pilots are compared; tests include stability of ignition and combustion-flame shape and its adjustment, as well as flame stability after combination with the main burner. The new pilot apparently shows a much better performance than the commercial one. Figure 4 further illustrates the good stability of the new pilot firing either NG or COG as fuel. In addition, the new pilot never blows off when it is mounted on the main burner, guaranteeing a positive result for integration of the locally purchasable UV-plug and amplifier combination during various function tests.

1.2) Performance testing of a larger scale gas-fired regenerative burner

In addition to applying constant-velocity theory for burner-body scale-up work, the heated objects inside the furnace must be taken into consideration. In our first attempt, in a coil-wire bell furnace, the front of the flame is limited so as not to impinge on the inner shell when the scale-up burner is mounted on the outer shell of the furnace. Therefore, the flame length has to be shorter than 1 m, and the width is designed to be no more than 20 cm. To further avoid the flame occasionally impinging directly on the inner wall of the furnace, a rectangular burner tile is designed to confine the flame within an acceptable width. A 25 x 10^4 Kcal/hr gas-fired burner assembly based on the above design criteria is shown in Figure 5.

To confirm the operating conditions of the 25 x 10^4 Kcal/hr regenerative burner, investigation includes measurement of the flame length and flame stability to identify how to mount the regenerative burner properly onto the furnace without damaging the regenerator and inner shell of the furnace. The parameters of the investigation are:

1. Capacity of burner: 25 x 10^4 Kcal/h
2. Loading: 25~100%gas fuel
3. Fuel supply ratio: F1= 40~100%; F2= 0~60%
4. Excess air:10%
5. Fuel: NG; COG.

Test results indicate that when the scale-up burner is applied in the restricted combustion chamber, the flame length and width must be confined at 60cm and 10cm, respectively. Another experiment was conducted to draw out the window of operating conditions for the scale-up burner, which is defined as 10%excess air and turn-down ratio around 1:4. Test results also reveal that the operating condition for burner inlet pressure should be within the turn-down range when we adopted Øair= 48mm, $Ø_{F1}$= 9mm, and $Ø_{F2}$= 9mm orifice plate.

2) Applications of Regenerative burners to industrial furnaces

Dissemination of regenerative combustion technology first has to convince local industries that highly efficient heat recovery has been realized; therefore, the following two demonstrative collaborations with steel industries were necessary to discover interfacial difficulties with existing furnaces during replacement of regenerative burners. Lessons gained from the retrofit indicate that, unless designing complete new furnaces, there are restrictions in application of HRS to existing furnaces. Existing furnaces with fewer than 4 burners and without heat recovery can be retrofitted and experience pay-back within two years.

2.1) Continuous soaking furnace

A local hot-rolling line is utilized to mill steel billet into long steel bar using rough mill and continuous mill in sequence; the square billet has relatively shorter length (2.8 m) and a larger cross-section (130 mm x 130 mm). The temperature of the billet is first raised to rolling temperature (> 1,000 C) through a reheating furnace, and the billet is transferred to the rough mill for primary milling and elongation to 25.6 m in length by 48.5 mm in diameter. Finally, the steel bar is charged to a continuous mill for secondary milling to produce semi-products with diameters less than 13mm.

For both rough mill and continuous mill, one of the major concerns is keeping the temperature difference between the head and tail of the bar as small as possible, because yield strength of the steel is usually inversely proportional to its temperature. A huge temperature difference may cause extra wear on the mill, unexpected shutdown of equipment, and at worst, a break of the roller.

Although a reheating furnace assures uniform temperature distribution across the billet, it inevitably loses energy continuously due to radiative heat transfer from its hot surface to cold surroundings. On the other hand, faster rolling speed in the rough mill (about 2 m/sec), smaller surface area, and shorter bar length could minimize the temperature difference. Nevertheless, slow rolling speed is often applied to continuous mill (about 0.2 – 0.4 m/sec), and a longer bar length (more than 20 m) results in a dramatic temperature gradient between the head and the tail of the bar. Therefore, a gas-firing soaking furnace is proposed to fit between the rough mill and continuous mill to reduce the temperature difference [8].

Although the distance between the rough mill and the first stand of the continuous mill is 36.5 m, because it has to reserve space for the rolling table and crop/shear arrangement, quite limited space is available for the soaking furnace. Therefore, a roller hearth soaking furnace 14.4 m long, with 0.63-m inner width and 0.965-m inner height, is finally designed, fabricated, installed and tested by ERL/ITRI, as shown in Figure 6. The inlet and exit of the soaking furnace are located 15.6 m and 30 m away from the rough mill and are equipped with 8 pairs of 100,000 kcal/hr HRS burners supplied by NFK (Nippon Furnace Kogyo, Japan); a side view of the HRS installation is shown in Figure 7. Inside the furnace, four independent temperature zones are applied and Kubota Corporation supplies 24 heat-resistant rollers. The maximum operating temperature is 1,200 C, and an NO_x level less than 150 ppm at 6% O_2 in flue is achieved by adopting staging fuel technology. After performance tests, the average temperature difference is reduced from 100–160 C to 60–80 C [10].

2.2) Bell furnace wire-coil annealing plant

In this study, we installed HRS burners onto a bell furnace to replace the original burner system that consisted of 12 high-speed burners. The total firing capacity of the original system was 120×10^4 Kcal/hr, and heat recovery was done by a heat exchanger able to heat the combustion air to 200 C. Previous stack testing showed that the exhaust gas was hotter than 350 C, and NOx emissions were slightly in violation of regulations. To meet the requirements for heat input, energy savings and inner space in the furnace, we decided to install 4 pairs of regenerative burners, two pairs each onto the upper and lower layers of the furnace. Since the capacity of the new burner is 25×10^4 Kcal/hr for each pair, the total capacity of heat input theoretically is 17% less than the original, but system performance is expected to exhibit the advantages listed below.

1. Exhaust gas temperature is lower than 250 C;
2. NOx emissions are lower than 150 ppm; and,
3. Heat recovery efficiency is greater than 70% (original recuperator efficiency was less than 35% in job site)

The function of a wire-coil annealing furnace is to precede a heat treatment for steel materials in order to obtain desired mechanical properties; this is a basic requirement for burner replacement. In addition, to match job-site application, the piping design for regenerative burners should meet the criteria below.

1. Weight of a pair regenerative burners must be less than 625 Kg;
2. Layout of burner and piping should take space limitations into consideration;
3. Flame front should not directly impinge on inner lid under maximum loading;

4. Burner should be able to maintain stable combustion for COG fuel supplied from plant side;
5. Burner should match the original heat pattern; and,
6. NOx< 150 ppm (d.,3% O_2).

The layout of burner and piping is shown in Figure 8. Four pairs of regenerative burners are equivalently installed at upper and lower levels, and the burners are tangentially mounted onto the furnace body to introduce high-temperature flue gas into the space between the inner and outer heating lid. To avoid temperature differences in the upper and lower sections of furnace caused by the buoyancy effect of high-temperature flue gas, the lower burners are located as low as possible, and the upper ones are located right in a middle section of furnace. In order to select the correct piping and space layout for the job site in advance, two-dimensional drawings were created to secure proper arrangement. New regenerative burners are to be installed in March, and the partial job site is shown in Figure 9.

CONCLUSION

Preheated air hotter than 800 C generated through a bed of honeycomb ceramic regenerators is an innovative way to drive human technologies across the 21st century. HiTAC is just one example of combustion applications that exhibit the advantages of stabilized flame, low NOx levels and uniform temperature distribution. ERL/ITRI has achieved a critical mass and is developing regenerative burners for gas-fired combustion systems; in this effort, industrial collaboration is the key to meaningful research. By completing development of these burners, ERL/ITRI is building up simulation techniques in order to design new heating furnaces that employ HiTAC advantages.

ACKNOWLEDGEMENT

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Table 1. Energy savings potential for industrial furnaces using HiTAC Technology

Equipment	Rate of improvement in thermal efficiency (%)	Energy Savings Rate (%)
Melting Furnace	50%	34%
Reheating Furnace		
Heat Treatment Furnace		
Firing Furnace		
Drying Furnace		
Furnace for chemical industry		
Petroleum Heating Furnace	15% (78–90%)	13.3%
Industrial Boiler	6% (85–90%)	5.6%

*Thermal efficiency (**ƒ**) = (sensible heat of materials heating / heat of combustion of fuel) x 100%. Energy saving rate = (1– **ƒ** before improvement / (**ƒ** after improvement) x 100%*

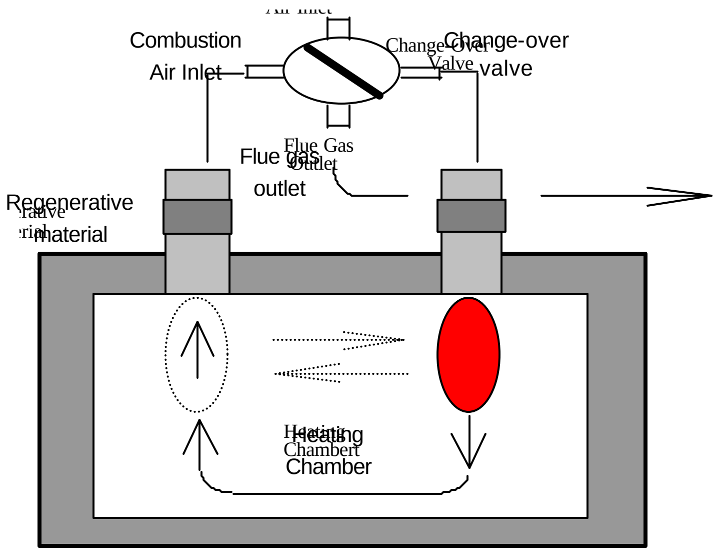

Figure 1. Schematic of high temperature air combustion (HiTAC).

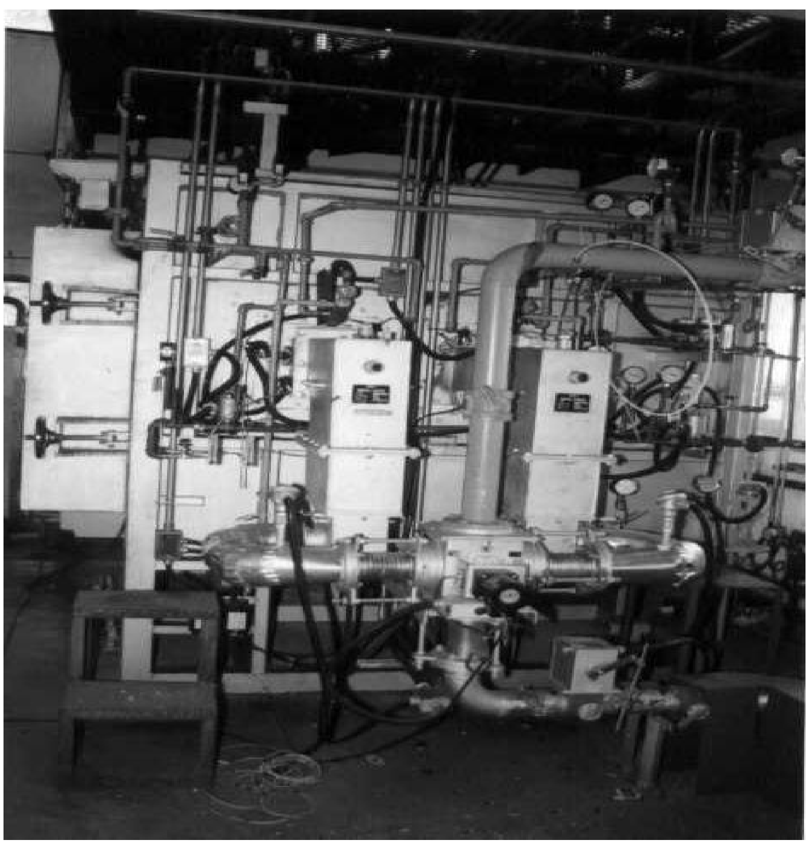

Figure 2. Testing facility of HiTAC research in ERL/ITRI.

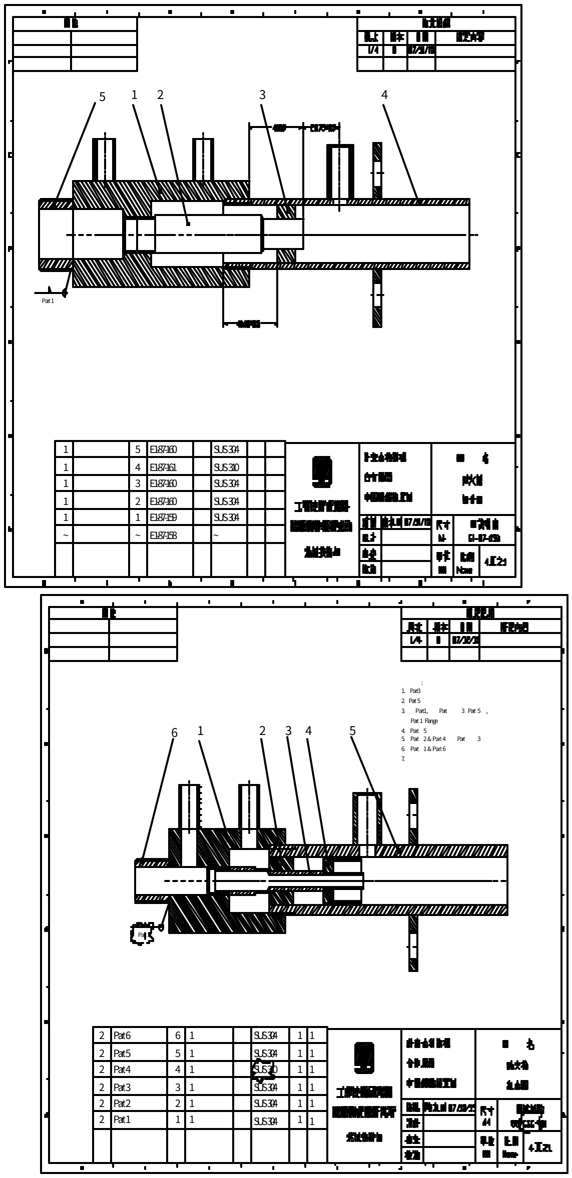

Figure 3. Design drawing of commercial (L) and new (R) pilots.

Figure 4. Flames of the new pilot firing NG (R) and COG (L).

Figure 5. Side (L) and front (R) views of regenerative burner, 25 x 10^4 Kcal/hr

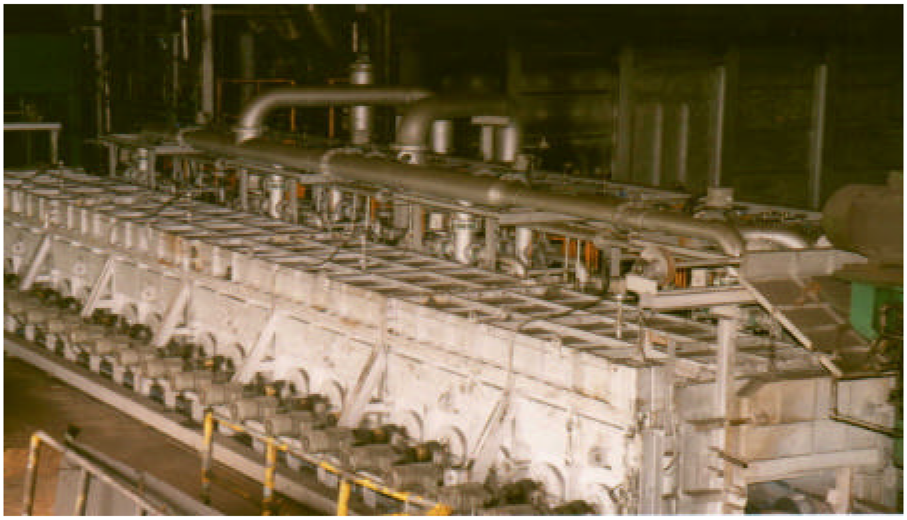

Figure 6. Top view of Continuous Soaking Furnace with HRS.

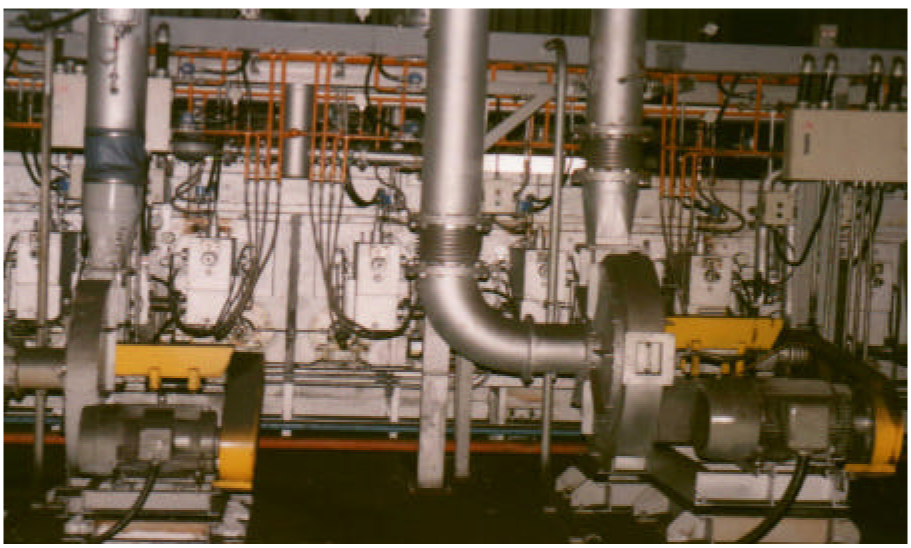

Figure 7. A view of regenerative burners

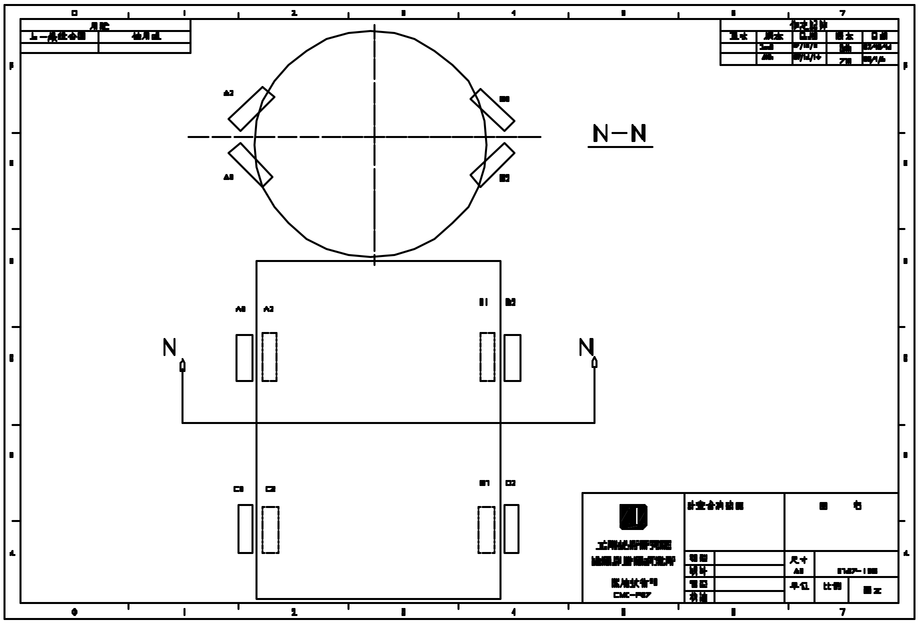

Figure 8. Arrangement of regenerative burners in wire coil annealing furnace.

Figure 9. Site jobs of Conventional Bell Annealing Furnace